US010704728B2

(12) **United States Patent**
Free et al.

(10) **Patent No.: US 10,704,728 B2**
(45) **Date of Patent: Jul. 7, 2020**

(54) **PIPE LINER AND METHOD OF MAKING SAME**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 182 days.

(21) Appl. No.: **15/926,325**

(22) Filed: **Mar. 20, 2018**

(65) **Prior Publication Data**

US 2019/0293223 A1 Sep. 26, 2019

(51) **Int. Cl.**

F16L 55/16 (2006.01)
F16L 55/165 (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***F16L 55/1656*** (2013.01); ***B29C 63/0021*** (2013.01); ***B29C 65/5042*** (2013.01); ***B29C 65/62*** (2013.01); ***B29C 66/7234*** (2013.01); ***B29C 67/0018*** (2013.01); ***B32B 1/08*** (2013.01); ***B32B 5/022*** (2013.01); ***B32B 5/26*** (2013.01); ***B32B 7/03*** (2019.01); ***B32B 7/08*** (2013.01); ***F16L 55/1651*** (2013.01); *B29L 2023/006* (2013.01); *B32B 2305/10* (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC F16L 55/1656; F16L 55/1651
USPC 138/97, 98; 405/150.1, 184.2
See application file for complete search history.

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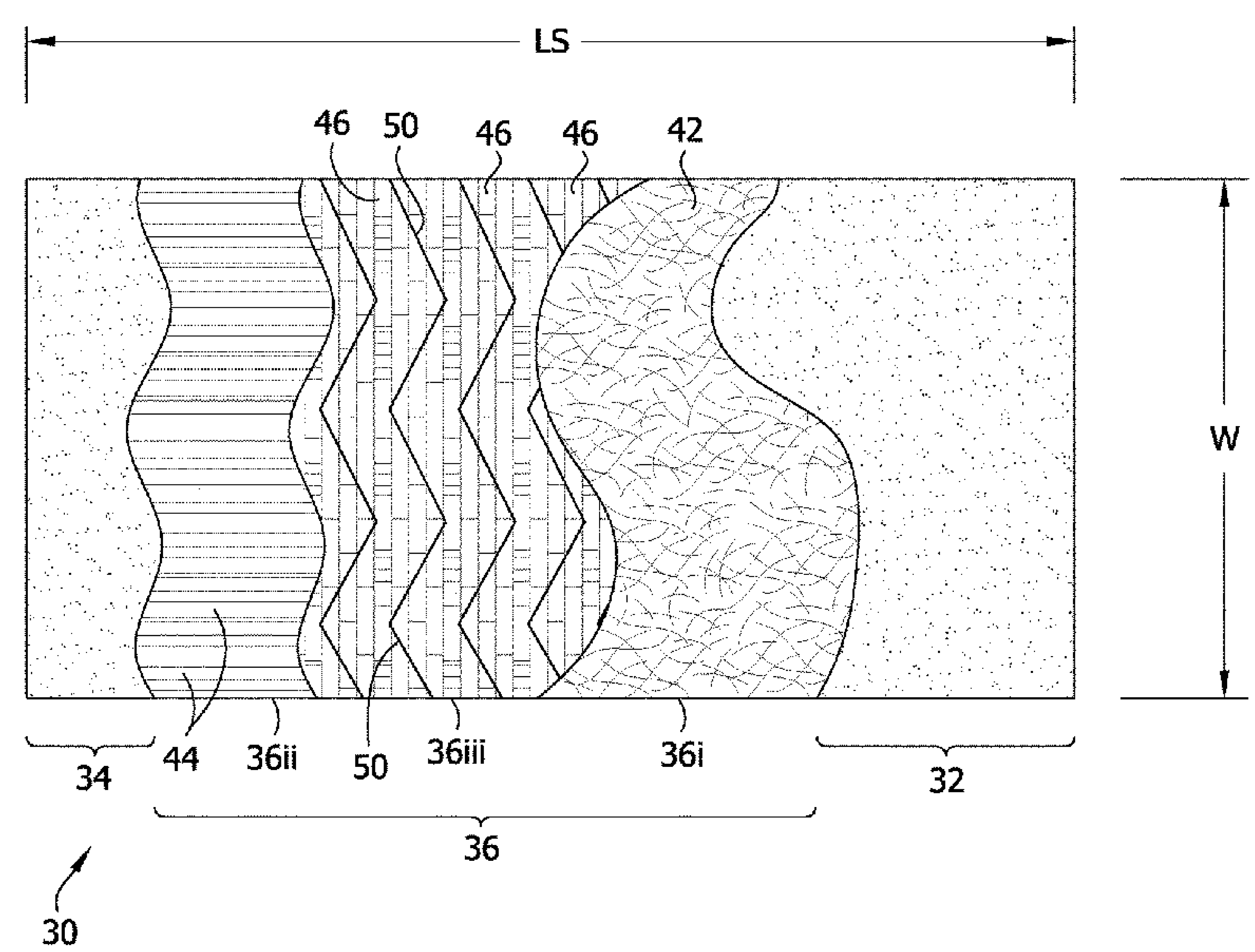
(57) **ABSTRACT**

An eversion liner for lining a pipe includes an impermeable outer portion, inner and outer strength portions inside the impermeable outer portion, and a middle portion including at least one felt layer radially between the inner and outer strength portions. At least one of the inner and outer strength portions is formed from a unitary sheet of strength material that includes parallel chopped strands of fiber. The longitudinal edge margins of the sheet of strength material are positioned in overlapping engagement and joined together by joining structure. The parallel chopped fibers can be oriented transverse to the length of the liner. The joining structure can prevent reduction in a width of the overlapped edge margins as the liner expands during eversion.

20 Claims, 3 Drawing Sheets



(51) **Int. Cl.**

B32B 7/03	(2019.01)
B29C 63/00	(2006.01)
B29C 65/50	(2006.01)
B29C 65/62	(2006.01)
B29C 65/00	(2006.01)
B29C 67/00	(2017.01)
B32B 1/08	(2006.01)
B32B 5/02	(2006.01)
B32B 5/26	(2006.01)
B32B 7/08	(2019.01)
B29L 23/00	(2006.01)

(52) **U.S. Cl.**
CPC ... *B32B 2305/22* (2013.01); *B32B 2307/7265* (2013.01); *B32B 2597/00* (2013.01)

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FIG. 1

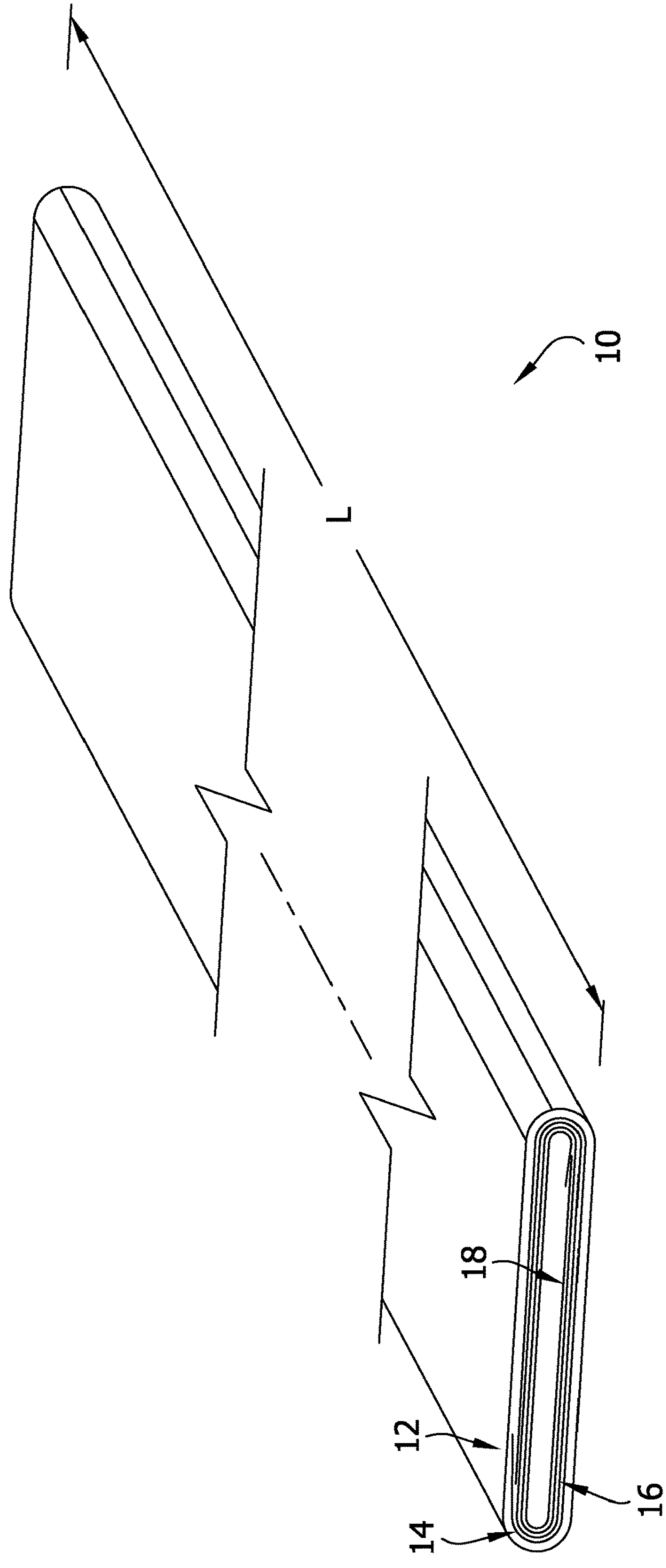
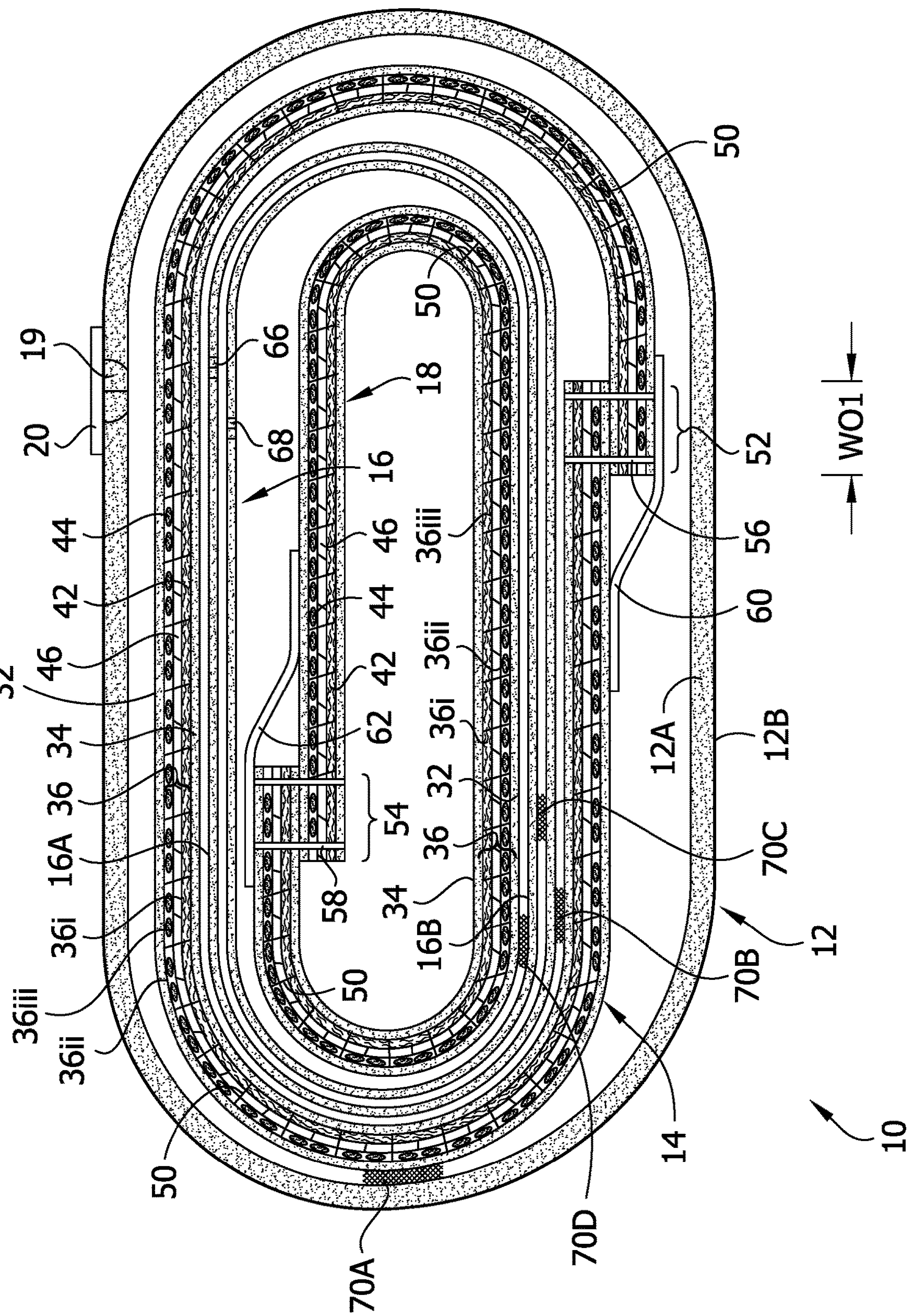


FIG. 2



10
12
12A
12B
14
16
16A
16B
18
19
20
32
34
36
36i
36ii
36iii
42
44
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52
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70A
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70C
70D
WO1
WO2

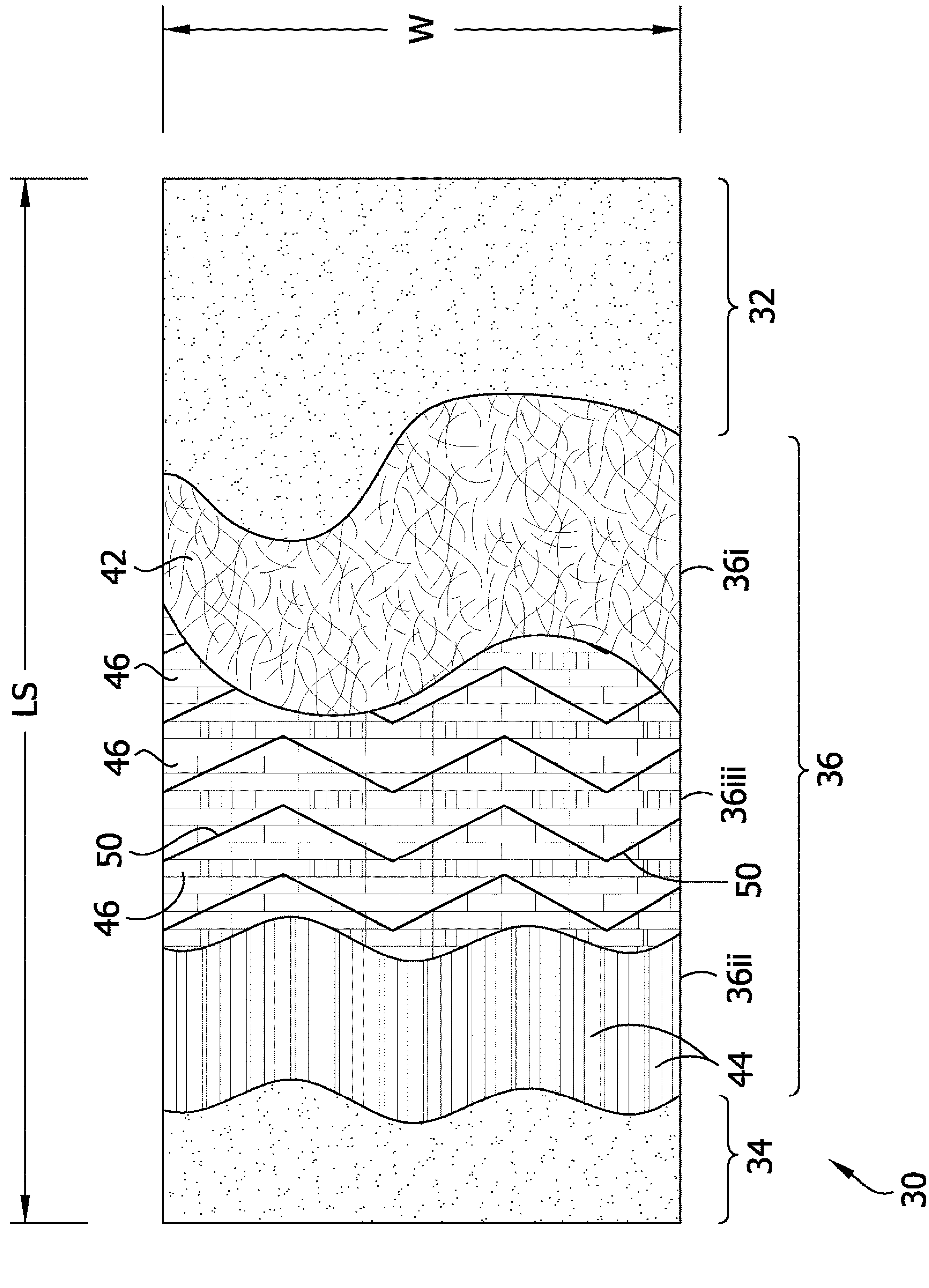

FIG. 3

PIPE LINER AND METHOD OF MAKING SAME

FIELD

The present invention generally relates to a cured-in-place pipe liner and, more specifically, to cured-in-place pipe liner comprising strengthening fibers.

BACKGROUND

Over time or because of a particular event or condition (e.g., seismic activity, exposure to excessive or uneven loads or moments, poor compaction, crown corrosion, corrosive soil, etc.), the structural integrity or capacity of force mains, other pipes, and like structures may diminish. For example, such items may crack, corrode, deteriorate, and the like. Damage to a pipe is particularly problematic when the pipe is used to carry a high pressure fluid because the pressurized fluid can impart significant forces, particularly in the hoop direction, on the pipe. Different methods of repairing or otherwise strengthening damaged pipes and other items are known. For example, reinforced fabric liners can be attached to one or more portions of a pipe interior. In cured-in-place pipe (CIPP) lining applications, liners are impregnated with a curable resin or epoxy, positioned along the interior surface of a host pipe, and allowed to cure, thereby forming a watertight barrier between the host pipe and the pipe interior. Various techniques for positioning a CIPP liner inside a host pipe (e.g., eversion, pull-in and inflate, etc.) and curing the liner (e.g., steam curing, ultraviolet light curing, etc.) are known. In addition, CIPP liners have been formed from various materials that have been constructed in many different ways. For example, it is known to form pressure-bearing liners from mats and fabrics that are laden with strengthening fibers such as glass fibers, etc.

SUMMARY

In one aspect, an eversion liner for lining a pipe comprises an outer impermeable portion having an interior. The outer impermeable portion comprises a fluid-impermeable material. The fluid impermeable material is formed into a longitudinally extending tube. The liner comprises inner and outer strength portions. The outer strength portion is located in the interior of the outer impermeable portion. Each of the inner and outer strength portions has an interior. Each of the inner and outer portions is arranged to form a respective longitudinally extending tube and comprises strengthening fibers. At least one of the inner and outer strength portions comprises a unitary sheet of strength material. The sheet of strength material has a width and opposite first and second longitudinal edge margins spaced apart along the width. The sheet of strength material comprises chopped strands of fiber oriented generally parallel to one another and distributed along the sheet of strength material. The first and second longitudinal edge margins of the sheet of strength material are positioned in overlapping engagement. The at least one of the inner and outer strength portions comprises joining structure connecting the first and second longitudinal edge margins of the sheet of strength material together in overlapped relation to form a longitudinal overlap portion extending parallel to a length of the at least one of the inner and outer strength portions. A middle portion has an interior. The middle portion comprises felt. The felt is formed into a longitudinally extending tube. The middle portion is located in the interior of the outer strength portion. The inner strength portion is located in the interior of the middle portion.

In another aspect, a method of manufacturing a liner for lining a pipe comprises forming a first strength tube comprising strengthening fibers. At least one felt tube is formed around the first strength tube. A second strength tube comprising strengthening fibers is formed around the at least one felt tube. An impermeable tube is formed around the second strength tube. At least one of the steps of forming the first strength tube and forming the second strength tube comprises: arranging a unitary sheet of strength material so that a width of the sheet extends in a hoop direction of the respective one of the first strength tube and the second strength tube. The sheet of strength material comprises chopped strands of fiber oriented generally parallel to one another and distributed along the sheet of strength material. First and second longitudinal edge margins of the sheet are joined together in overlapped relation to form a longitudinal overlap portion extending parallel to a length of the respective one of the first strength tube and the second strength tube.

Other objects and features will be in part apparent and in part pointed out hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a fragmentary perspective of a liner;

FIG. **2** is a schematic cross section of the liner; and

FIG. **3** is a schematic fragmentary top plan view of a sheet of material for forming a strength layer of the liner.

Corresponding reference characters indicate corresponding parts throughout the drawings.

DETAILED DESCRIPTION

Referring to FIG. **1**, one embodiment of a liner for being cured in place inside a host pipe (not shown) is generally indicated at reference number **10**. The illustrated liner **10** is configured to be installed by eversion. It is understood that aspects of the disclosure could be adapted for use with liners that are installed by other methods without departing from the scope of the invention. The liner **10** has a first end and a second end spaced apart along a length L of the liner. As will be explained in further detail below, the liner **10** comprises an outer portion **12**, an outer strength portion **14** nested in the outer portion, a middle portion **16** nested in the outer strength portion, and an inner strength portion **18** nested in the middle portion. Each of the outer portion **12**, the outer strength portion **14**, the middle portion **16**, and the inner strength portions **18** comprises one or more flexible tubes in the illustrated embodiment. The tubes are nested in a concentric arrangement to form the liner **10**. Prior to installation, the inner strength portion **18** defines the interior of the liner **10**, but after the liner is everted into a host pipe, the outer portion **12** defines the liquid flow passage of the installed liner. Throughout this disclosure the terms "inner" and "outer" (as well as other similar terminology) are used in reference to the arrangement of the liner **10** prior to eversion and as shown in the drawings. As will be described in further detail below, the illustrated liner **10** is configured so that the discrete portions **12**, **14**, **18**, **16** are connected to one another so that liner can be reliably everted into a host pipe as a single unit. Furthermore, as discussed below, the strengthening portions **14**, **18** of the liner **10** are configured to provide the installed liner with standalone pressure-bearing capacity and, moreover, do so substantially without creating wrinkles in the installed liner.

Referring to FIG. **2**, the outer portion **12** has a length that extends from the first end to the second end of the liner **10** and comprises a coated felt that is formed into a tube that extends along the length of the outer portion. The outer portion **12** comprises an inner layer of felt **12**A (e.g., non-woven threads that are needle-punched, matted, condensed, or otherwise pressed together) and a fluid-impermeable coating **12**B. The coating **12**B can be formed by a polymer that is applied to the felt **12**A in fluidic form and then cured to permanently bond to the felt. Alternatively, the coating **12**B can be formed from an impermeable polymer film that is permanently bonded to the felt **12**A using an adhesive, heat, etc., such that there is a bond between the coating and the felt that is substantially continuous along substantially the entire surface area of the felt. The felt **12**A comprises a resin-impregnable material such as polyester felt. The impermeable coating **12**B can comprise a polymer, for example a polyolefin, such as polyethylene or polypropylene; a vinyl polymer, such as polyvinylchloride; or a polyurethane. Exemplary methods of forming a coated felt outer portion **12** are described in U.S. Pat. Nos. 7,857,932, 7,261,788, and 7,238,251, each of which is hereby incorporated by reference in its entirety.

To form the outer portion **12** to a desired length, multiple sheets of coated felt are arranged end-to-end and joined together at adjoining end margins. The sheet of coated felt is folded into a tube such that side margins of the sheet engage one another, the felt layer **12**A defines the interior of the tube, and the impermeable coating **12**B defines the exterior of the tube. The side margins are joined together at a seam **19** (e.g., a butt seam, an overlap seam, etc.) by joining structure such as stitching, an adhesive bond, a flame bond, etc. In the illustrated embodiment, the seam **19** extends lengthwise of the outer portion **12**. A fluid-impermeable tape **20** is applied to the exterior surface of the outer portion **12** along the length of the seam **19**. The tape **20** can be heat-boned or chemically bonded to the exterior surface of the outer portion **12** in certain embodiments. The tape **20** seals the seam **19** so that the outer portion **12** provides a fluid-impermeable barrier.

The coating **12**B on the outer portion **12** is preferably airtight and the tape **20** provides a fluid seal of the seam **19** so that the liner can be everted and expanded into contact with the pipe by fluid pressure. Suitably, the coated felt that forms the outer portion **12** is configured to stretch circumferentially when the liner **10** is expanded radially from a first diameter to a larger second diameter. When the liner **10** expands radially during installation, the coated felt stretches circumferentially while the seam **19** remains intact and sealed by the tape **20**. After being everted into a host pipe, the coating **12**B defines a substantially smooth, watertight surface, which extends continuously along the interior of the installed liner **10**.

In the illustrated embodiment, each of the strength portions **14**, **18** is formed from the same type of material and is assembled in the same general manner. It will be understood that, in other embodiments, the strength portions could have different configurations without departing from the scope of the invention. Each strength portion **14**, **18** has a length extending from the first end to the second end of the liner **10** and comprises a multilayer composite material formed into a tube that extends along the length of the respective strength portion. The outer strength portion **14** extends longitudinally through the interior of the outer portion **12** and defines a longitudinal interior of its own. The middle portion **16** extends longitudinally through the interior of the outer strength portion **14**, and the inner strength portion **18** extends longitudinally through the interior of the middle portion. Although the illustrated liner **10** includes an outer strength portion **14** concentrically arranged between an outer portion **12** and a middle portion **16** and an inner strength portion **18** nested inside the middle portion, other embodiments can include other numbers and arrangements of strength portions.

Referring to FIG. **3**, each strength portion **14**, **18** is formed from a sheet **30** of a multilayer composite fabric. FIG. **3** has been broken away to illustrate its constituent layers. It is understood that, in order to be of a desired total length, each strength portion **14**, **18** could also be formed multiple sheets that are connected together in an end-to-end arrangement. Each sheet **30** has first and second end margins spaced apart along a length LS. In the assembled liner **10**, the length LS of the sheet **30** extends along a length L of the liner. Each sheet **30** also has first and second side margins spaced apart along a width W. In the assembled liner **10**, the width W of each sheet extends in the hoop direction (e.g., about the circumference) of the liner. To form each of the strength portions **14**, **18**, the respective sheet is folded into a tube such that the side margins engage one another and are joined together at a respective seam **52**, **54** (FIG. **2**) that is circumferentially offset from the other seam and from the seam **19** of the outer portion **12**.

The multilayer sheet **30** comprises a first impregnation layer **32** formed from resin-impregnable material, a second impregnation layer **34** formed from resin-impregnable material, and a strength layer **36** that includes strengthening fibers received between the impregnation layers. In the illustrated embodiment, the strength layer **36** is also configured to be impregnated with resin or other curable polymer. Other strength portions can comprise other multilayer materials (e.g., a multilayer material comprising a single impregnation layer and one or more strength layers; two or more strength layers and impregnation layers; etc.) or a single-layer material.

In the illustrated embodiment, each of the impregnation layers **32**, **34** is formed from a resin-impregnable felt, e.g., a polyester felt, which extends continuously along the length LS and width W of the sheet **30**. In the illustrated embodiment, the non-woven fibers of the felt layers **32**, **36** are needled to the strength layer **36** to secure the strength layer between the felt layers. Needling the felt layers **32**, **34** to the strength layer **36** enables the composite fabric **30** to be handled as a unitary sheet of material when the liner **10** is assembled. The felt layers **32**, **34** provide good resin-impregnation characteristics and also provide structure that is suitable for being handled by industrial sewing machines when forming the composite fabric **30** into the respective tube **14**, **18**. An exemplary material for the felt layers **32**, **34** is polyester felt. Such felts are used by Aegion Corporation of St. Louis, Mo., in various cured-in-place pipe lining products such as, for example, InsituMain® pipe liners. Other types of felts or other resin-impregnable materials can be used to form the impregnation layer(s) of the strength portions without departing from the scope of the invention.

Suitably, the strength layer **36** comprises strengthening fibers, such as glass fibers, carbon fibers, etc. The strength layer **36** extends continuously along the length LS and width W of the fabric sheet **30**. In the illustrated embodiment, the strength layer **36** is formed from first, second, and third sublayers **36***i*, **36***ii*, **36***iii*, and each of the sublayers extends along the length LS and width W of the fabric sheet **30**. In the illustrated embodiment, the first sublayer **36***i* is a mat formed from randomly oriented chopped fibers **42** distributed throughout the strength layer **36**. The second sublayer **36***ii* is formed from continuous fibers **44** oriented generally parallel to the length LS and distributed throughout the strength layer **36**, and the third sublayer **36***iii* is formed from long oriented chop material containing long fibers **46** oriented generally parallel to one another and transverse to the continuous fibers and distributed throughout the strength layer. In the illustrated embodiment the sublayer of long oriented chopped fibers **46** is sandwiched between the sublayers of random oriented fibers **42** and continuous fibers **46**; however, other arrangements of the sublayers are also possible without departing from the scope of the invention. The different types of fibers **42**, **44**, **46** are illustrated schematically in FIGS. **2** and **3**. It will be understood that the strength layers can have other configurations in other embodiments

The chopped fibers **42** are matted together in random orientations to form the sublayer **36***i* of the strength layer **36**. The random oriented chopped fibers **42** are loosely held together in a mat such that they can shift relative to one another and allow the sublayer **36***i* to stretch circumferentially as the liner **10** expands radially. The random oriented fibers **42** are configured to enhance the strength of the respective strength portion **14**, **18** in a non-directional manner (e.g., the random oriented fibers strengthen the liner **10** in a hoop direction and also in other directions). Moreover, as described in further detail below, the mat of random oriented fibers **42** provides a backing structure to which the bundles of fibers **44**, **46** are secured to form the strength layer **36**. Securing the bundles of fibers **44**, **46** to the sublayer **36***i* of randomly oriented fibers **42** allows sheet material including the three sublayers **36***i*, **36***ii*, **36***iii* of strengthening fibers to be handled independently during manufacturing before it is needled or otherwise secured to one or both of the felt layers **32**, **34**.

In the illustrated embodiment the continuous fibers **44** are arranged in bundles that extend continuously along the length LS of each sheet **30**. The bundles of continuous fibers **44** are spaced apart along the width W of the sheet **30**. When the sheet is formed into the respective one of the outer and inner strength portions **14**, **18**, the bundles of continuous fibers **44** are spaced apart about the circumference of the respective strength portion. The bundles of continuous fibers **44** can move along the width W of the sheet **30** and about the circumference of the respective strength portion **14**, **18** so that each strength portion can stretch circumferentially when the liner **10** expands radially. The illustrated continuous fibers **44** form a one-bundle-thick sublayer **36***ii* of fibers, but in other embodiments the bundles of continuous fibers can be stacked to form a sublayer of continuous fibers that is more than one bundle in thickness. The continuous fibers **44** provide longitudinal reinforcement of the sheet **30** and thus provide longitudinal reinforcement of the liner **10**.

The long fibers **46** in the sublayer **36***iii* of the illustrated strength layer **36** extend generally parallel to the width W of the sheet **30**. More specifically, the long fibers **46** are arranged in bundles extending generally parallel to the width of the sheet. The individual long fibers **46** thus extend generally parallel to the bundles of which they are a part. The bundles of long oriented chop fibers **46** are spaced apart from one another along the length LS of the sheet **30** to form the middle sublayer **36***iii* of the strength layer **36**. The illustrated long fibers **46** form a one-bundle-thick sublayer **36***iii* of fibers, but in other embodiments the bundles of chopped fibers can be stacked to form a sublayer that is more than one bundle in thickness. The illustrated bundles of long fibers **46** are oriented generally perpendicular to the bundles of continuous fibers **44**. In each of the assembled strength portions **14**, **18**, the bundles of long fibers **46** are spaced apart along the length of the respective strength portion and extend in the hoop direction (about the circumference of the respective strength portion) to circumferentially reinforce the liner **10**. In the illustrated embodiment, each bundle of long fibers **46** extends about the entire circumference of the respective strength portion **14**, **18**. Each long fiber **46** has a length that is long in comparison to random oriented fibers **42**, but is less than the width W of the sheet **30** and the circumference of the respective strength portion **14**, **18**. The fibers **46** can all have the same length or have different lengths without departing from the scope of the invention. Although the chopped fibers **46** are arranged in bundles in the illustrated embodiment, circumferentially oriented chopped fibers can also be supported in the strength layer without being arranged in bundles in other embodiments.

Referring to FIG. **2**, because the bundles in each sublayer **36***iii* are formed from long fibers **46** instead of continuous fibers, each of the strength portions **14**, **18** can stretch circumferentially when the liner **10** expands radially. In each strength layer **36**, the long fibers **46** are held together loosely so that they can move relative to one another within each respective bundle in directions parallel to their lengths, along the circumference of the liner **10**. Since the long fibers **46** can move relative to one another along their lengths, the middle sublayer **36***iii* of the strength layer **36** of each strength portion **14**, **18** can be stretched circumferentially when the liner **10** expands radially. Since the felt layers **32**, **34** and inner and outer sublayers **36***i*, **36***ii* of the strength layer **36** are also formed from circumferentially stretchable material as explained above, each strength portion **14**, **18** is configured to stretch circumferentially as the diameter of the liner **10** increases when it is expanded during eversion.

In the illustrated embodiment stitching **50** loosely secures the bundled long fibers **46** and bundled continuous fibers **44** to the mat of random oriented fibers **42** to form the strength layer **36**. But in other embodiments, other ways of loosely securing the strengthening fibers can be used without departing from the scope of the invention. The stitching **50** is sufficiently loose to permit the long fibers **46** within each circumferential bundle to move relative to one another along the circumference of the strength layer **36** but is sufficiently strong to hold the fibers **42**, **44**, **46** of the strength layer together during manufacturing. The stitching **50** is also configured to allow the random oriented fibers **42** to shift and the bundles of continuous fibers **44** to move circumferentially of the liner **10** during installation. Thus, the stitching **50** is configured to maintain the general arrangement of the strengthening fibers **42**, **44**, **46** during installation while permitting the strengthening fibers to move as required to facilitate circumferential stretching of the strength layer **36** when the liner **10** is radially expanded.

In each strength portion **14**, **18**, the composite fabric sheet **30** is folded so that the side margins of the fabric sheet overlap one another at a respective seam **52**, **54**. Each seam thus comprises an overlap portion that extends generally along the length L of the liner **10**. In the illustrated embodiment, overlap stitching **56**, **58** secures the overlapping side margins of the respective sheet **30** together in each strength portion **14**, **18**. In other embodiments, the overlapped side margins could be secured together by other types of joining structure, e.g., a heat bond, an adhesive bond, etc.

Each overlap portion **52**, **54** has a width WO**1**, WO**2**. In certain embodiments each width WO**1**, WO**2** is in an inclusive range of from about 1.5 inches (3.8 cm) to about 2.5

inches (6.46 cm). Widths in this range can be suitable for using an industrial sewing machine to stitch the overlap portion **52**, **54**. However, it will be understood that overlap portions of other widths can be used in other embodiments. The stitching **56**, **58** allows the tube to expand circumferentially without breaking the respective seam **52**, **54**. Because the impregnation layers **32**, **34** and strength layer **36** are configured to stretch circumferentially, when each strength layer **14**, **18** expands from a first diameter to a larger second diameter during installation, the width WO**1**, WO**2** of the respective longitudinal overlap portion **52**, **54** does not decrease. Instead the width WO**1**, WO**2** of the respective longitudinal overlap portion **52**, **54** either stays the same or increases, increasing proportionally with the increase in circumference of the respective strength portion **14**, **18**. The stitching **56**, **58** holds the longitudinal side margins of the sheet **30** together at each seam **52**, **54** even after the diameter of the respective strength portion **14**, **18** increases.

In one or more embodiments, each overlap portion **52**, **54** is reinforced with a reinforcing strip **60**, **62**. The reinforcing strips **60**, **62** can comprise any suitable reinforcing material. In certain embodiments, each reinforcing strip **60**, **62** comprises a two-layer material comprising a felt layer and a fibrous layer that is needle punched or otherwise secured to the felt layer. In one embodiment, the reinforcing strip **60**, **62** is attached to the outer felt layer **34** of the respective strength portion **14**, **18** at locations on opposite sides of the overlap seam **52**, **54**, e.g., by flame bonds, adhesive bonds, stitching, etc. In certain embodiments, each reinforcing strip **60**, **62** extends continuously along the length of the respective strength portion **14**, **18**. Each reinforcing strip **60**, **62** can be bonded to the outer felt layer **34** of the respective strength portion **14**, **18** on opposite sides of the seam **52**, **54** continuously along, or at spaced apart locations along, the length of the respective strength portion.

The middle portion **16** has a length extending from the first end to the second end of the liner **10** and comprises felt formed into a tube having an interior. As explained above, the middle portion **16** extends longitudinally through the interior of the outer strength layer **14**, and the inner strength layer **18** extends longitudinally through the interior of the middle portion. The middle portion **16** comprises one or more discrete felt layers **16**A, **16**B, each formed into a discrete felt tube. The felt tubes **16**A, **16**B are each configured to be impregnated with a curable polymer such as resin. In the illustrated embodiment, the middle portion **16** comprises two discrete felt tubes **16**A, **16**B that are arranged concentrically. It will be understood that the middle portion of other liners can have other numbers of felt tubes (for example zero or more felt tubes, e.g., a number of felt tubes in an inclusive range of from 1 to 5, etc.)

Each discrete felt layer **16**A, **16**B comprises a sheet of felt (or a plurality of sheets of felt arranged end-to-end) having first and second end margins spaced apart along a length that extends along the length of the middle portion **16** and first and second side margins spaced apart along a width that extends about a circumference of the middle portion. Each felt sheet **16**A, **16**B is folded into a tube such that the side margins of the sheet engage one another and are joined together at a respective seam **66**, **68**. In the illustrated embodiment, the side margins are joined together at a stitched butt seam, but the side margins can be joined together in other ways without departing from the scope of the invention. Suitably, each seam **66**, **68** is configured to withstand circumferential stretching of the middle portion **16** as the liner **10** expands radially during installation. In one or more embodiments, all of the seams **19**, **52**, **54**, **66**, **68** in the liner **10** are offset circumferentially from one another.

In the illustrated embodiment, the outer portion **12**, the outer strength portion **14**, each of the middle felt tubes **16**A, **16**B, and the inner strength portion **18** each comprises a respective tube of the liner **10**. The individual tubes **12**, **14**, **16**A, **16**B, **18** included in the liner **10** are bonded together at bonds **70**A-**70**D. In one or more embodiments, each of the bonds **70**A-**70**D extends continuously or intermittently along the length L of the liner **10**. The outer portion **12** of the liner is bonded to the outer felt layer **32** of the outer strength portion **14** at a bond **70**A; the inner felt layer **34** of the outer strength portion is bonded to the outer felt tube **16**A at a bond **70**B, the outer felt tube is bonded to the inner felt tube **16**B at a bond **700**; and the inner felt tube is bonded to the outer felt layer **32** of the inner strength layer **18** at a bond **70**D. Because the opposing surfaces the tubes **12**, **14**, **16**A, **16**B, **18** are all formed of felt material, the bonds **70**A-**70**D can comprise flame bonds. In other words, in the illustrated embodiment, each discrete tube **12**, **14**, **16**A, **16**B, **18** is flame bonded to an adjacent tube to form a unitary liner **10**. It will be understood that other types of bonds (e.g., adhesive bonds, a mix of flame bonds and adhesive bonds, etc.) can also be used to secure together two or more tubes of a liner in other embodiments.

In an exemplary method of manufacturing the liner **10**, the manufacturer folds a composite fabric sheet **30** into an inner strength tube **18** so that the longitudinal side margins overlap one another at an overlap seam **54**. The manufacturer guides the inner strength tube **18** through a stitching machine to stitch the side margins together along the overlap seam **54**. The manufacturer then bonds the reinforcing strip **62** to the overlap portion **54** using an adhesive bond, a flame bond, etc.

After forming the inner strength tube **18**, the manufacturer wraps one or more sheets of felt **16**A, **16**B around it to form the middle portion **16**. In one embodiment, the manufacturer guides each sheet of felt through a stitching machine to stitch together the longitudinal side margins at the seams **66**, **68**. Suitably, the manufacturer wraps each felt sheet so that the seams **66**, **68** are circumferentially spaced from the seam **54** of the inner strength tube **18**. Each felt tube **16**A, **16**B is also flame bonded to the tube that is received in its interior. For example, in the illustrated embodiment, the manufacturer flame bonds the felt tube **16**B to the inner strength portion **18** at flame bond **70**D and flame bonds the felt tube **16**A to the other felt tube at flame bond **70**C.

After the desired number of felt tubes is/are formed and flame bonded to the inner strength portion **18**, the manufacturer wraps another composite fabric sheet **30** around the middle portion **16** to form the outer strength tube **14**. The manufacturer folds the sheet **30** around the middle portion **16** so that the longitudinal side margins of the sheet overlap one another at an overlap seam **52**. Suitably, the manufacturer wraps the composite fabric sheet **30** so that the overlap seam **52** is circumferentially spaced from the overlap seam **54** and each of the seams **66**, **68**. The manufacturer guides the outer strength tube **14** through a stitching machine to stitch together the longitudinal side margins of the composite fabric sheet **30** along the overlap seam **52**. The manufacturer then bonds the reinforcing strip **60** to the overlap seam **52** using an adhesive bond, a flame bond, etc. The outer strength tube **14** is also flame bonded to the outer felt tube **16**A at a flame bond **70**B.

The manufacturer then wraps a sheet of coated felt around the outer strength tube **14** to form the outer tube **12**. Specifically, the manufacturer folds the coated felt around the outer strength tube **14** so that the longitudinal side margins engage one another and the coating **12**B defines the exterior of the tube. The manufacturer guides the coated felt tube **12** through a stitching machine to stitch together the side margins of the material at the seam **19**. The manufacturer then applies impermeable tape **20** along the seam **19** to seal the seam.

To install the liner **10** in a host pipe (not shown), the liner is initially impregnated with curable polymer such as resin. Various techniques for impregnating a liner with curable polymer are known or may become known, and any suitable technique can be used without departing from the scope of the invention. For example, a resin impregnation system is disclosed in U.S. Pat. No. 7,238,251, which is hereby incorporated by reference in its entirety. In one embodiment, the step of impregnating the liner **10** with resin is performed at a factory remote from the host pipe and the impregnated liner is transported to the site of the host pipe in a suitably climate controlled truck. In other embodiments, the crew could impregnate the liner **10** at the site of the host pipe without departing from the scope of the invention. Suitably, the step or impregnating the liner **10** with resin distributes resin throughout the felt layer **12**A of the outer tube **12**, each of the layers **32**, **34**, **36** of the outer strength tube **14**, each of the felt tubes **16**A, **16**B, and each of the layers **32**, **34**, **36** of the inner strength tube **18**, as well as through each of the reinforcing strips **60**, **62**.

After the liner **10** is impregnated with resin, the crew installs the liner inside the host pipe by everting the liner. In the eversion process, the liner **10** is turned inside out, advancing down the host pipe as more of the liner is everted. The eversion process presses the inner strength portion **18** against the interior surface of the host pipe and causes the coating **12**B of the outer portion **12** to become the interior surface of the lined pipe. Thus, after eversion is complete, the impermeable coating **12**B provides a resin barrier that prevents the resin in the liner **10** from escaping into the interior of the pipe. During the eversion process, the flame bonds **70**A-**70**D maintain secure connections among the discrete tubes **12**, **14**, **16**A, **16**B, **18** such that liner retains its structure and can be everted as a single unit. Various techniques for everting the liner **10** are known or may become known, and any suitable technique can be used without departing from the scope of the invention. For example, systems for everting a liner are disclosed in U.S. Pat. Nos. 9,453,597, 8,066,499, 7,866,968, and 7,766,048, each of which is hereby incorporated by reference in its entirety.

Prior to eversion, the liner **10** and each of the tubes **12**, **14**, **16**A, **16**B, **18** has a respective initial diameter. The eversion process stretches the liner **10** and each tube **12**, **14**, **16**A, **16**B, **18** from its initial diameter to a larger second diameter. As explained above, the arrangement of strengthening fibers **42**, **44**, **46** within each of the strength portions **14**, **18** allows the strength portion to stretch circumferentially without reducing the width WO**1**, WO**2** of the respective overlap portion **52**, **54**. The stretching of the liner **10** helps prevent wrinkles from forming as the liner is positioned in contact with the interior surface of the host pipe **10**. Thus, after eversion is complete, the impermeable coating **12**B forms a smooth surface along which liquid may flow with minimal drag. The continuous fibers **44** resist elongation of the liner **10**.

Once the liner **10** is positioned in continuous contact with the interior surface of the host pipe, the resin in the liner cures to form a cured-in-place liner along the interior surface of the host pipe. In certain embodiments, the resin cures in ambient conditions. In other embodiments, the crew cures the resin by directing a suitable form of curing energy, such as heat, ultraviolet radiation, etc., toward the resin impregnated liner **10**. Various techniques for curing a resin-impregnated liner are known or may become known, and any suitable technique can be used without departing from the scope of the invention. For example, curing systems are disclosed in several of the U.S. Patents incorporated by reference above, as well as in U.S. Pat. No. 7,360,559, each of which is hereby incorporated by reference in its entirety.

The cured resin strongly binds each of the tubes **12**, **14**, **16**A, **16**B, **18** together after the installed liner **10** is put into service. Furthermore, the strength layers **36** (in particular, the circumferentially oriented fibers **46**) of the inner and outer strength tubes **14**, **18** circumferentially reinforce the host pipe to withstand internal loads (e.g., internal fluid pressures, etc.) and/or external loads (e.g., seismic loads, etc.). As can be seen therefore, the liner **10** can be installed by eversion and provide a new, high strength pipe inside a host pipe that defines a substantially smooth, watertight flow passage.

Having described the invention in detail, it will be apparent that modifications and variations are possible without departing from the scope of the invention defined in the appended claims.

As various changes could be made in the above constructions and methods without departing from the scope of the invention, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An eversion liner for lining a pipe, the liner comprising:

an outer impermeable portion having an interior, the outer impermeable portion comprising a fluid-impermeable material, the fluid impermeable material being formed into a longitudinally extending tube;

inner and outer strength portions, the outer strength portion being located in the interior of the outer impermeable portion, each of the inner and outer strength portions having an interior, each of the inner and outer portions being arranged to form a respective longitudinally extending tube and comprising strengthening fibers, at least one of the inner and outer strength portions comprising a unitary sheet of strength material, the sheet of strength material having a width and opposite first and second longitudinal edge margins spaced apart along the width, the sheet of strength material comprising chopped strands of fiber gathered into bundles, the bundles being oriented generally parallel to one another and distributed along the sheet of strength material, each of the bundles extending in a direction from the first longitudinal edge margin to the second longitudinal edge margin of the sheet of strength material, the first and second longitudinal edge margins of the sheet of strength material being positioned adjacent one another and being attached to one another at a seam, the sheet of strength material being configured for being stretched radially from a first external diameter to a second external diameter larger than the first external diameter, the seam being constructed to hold the first longitudinal edge margin from moving in a circumferential direction relative to the second longitudinal edge margin as the liner tube is stretched radially from the first external diameter to the second external diameter; and

a middle portion having an interior, the middle portion comprising felt, the felt being formed into a longitudinally extending tube, the middle portion being located in the interior of the outer strength portion, the inner strength portion being located in the interior of the middle portion.

2. An eversion liner as set forth in claim **1**, wherein the chopped strands of fiber are arranged to strengthen the liner in a hoop direction of the liner.

3. An eversion liner as set forth in claim **1**, wherein the chopped strands of fiber extend generally parallel to the width of the sheet of strength material.

4. An eversion liner as set forth in claim **1**, wherein the sheet of strength material further comprises an inner felt layer and an outer felt layer, the chopped strands of fiber being sandwiched between the inner and outer felt layers.

5. An eversion liner as set forth in claim **4**, wherein the inner and outer felt layers are needle punched to the chopped strands of fiber.

6. An eversion liner as set forth in claim **4**, wherein one of the inner and outer felt layers is flame bonded to the middle portion.

7. An eversion liner as set forth in claim **1**, wherein the sheet of strength material further comprises continuous strands of fiber distributed along the sheet of strength material, the continuous strands of fiber being oriented parallel to one another and transverse to the chopped strands of fiber.

8. An eversion liner as set forth in claim **1**, wherein the sheet of strength material further comprises a mat of random oriented chopped fibers.

9. An eversion liner as set forth in claim **1**, wherein the longitudinal edge margins of the sheet of strength material are positioned in overlapping engagement the longitudinal to form an overlap portion having a width, the eversion liner being configured to be everted into a host pipe such that the at least one of the inner and outer strength portions expands from a first diameter to a larger second diameter without decreasing the width of the longitudinal overlap portion.

10. An eversion liner as set forth in claim **9**, wherein the longitudinal overlap portion of has a width of at least about 3.8 cm.

11. An eversion liner as set forth in claim **1**, wherein the seam comprises stitching.

12. An eversion liner as set forth in claim **1**, wherein the at least one of the inner and outer strength portions further comprises a reinforcing strip, the reinforcing strip extending along the longitudinal overlap portion and being attached to the sheet of strength material at locations adjacent each of the first and second longitudinal edge margins.

13. An eversion liner as set forth in claim **1**, wherein the middle portion comprises a plurality of discrete felt layers.

14. An eversion liner as set forth in claim **1**, wherein each of the discrete felt layers is flame bonded to an adjacent one of the other discrete felt layers.

15. An eversion liner as set forth in claim **1**, wherein the middle portion comprises a number of discrete felt layers in an inclusive range of from 1 to 5 discrete felt layers.

16. An eversion liner as set forth in claim **1**, wherein the fluid-impermeable material comprises coated felt.

17. An eversion liner as set forth in claim **1**, wherein the at least one of the inner and outer strength portions includes each of the inner and outer strength portions.

18. A. method of manufacturing a liner for lining a pipe, the method comprising:

forming a first strength tube comprising strengthening fibers;

forming at least one felt tube around the first strength tube;

forming a second strength tube comprising strengthening fibers around the at least one felt tube; and

forming an impermeable tube around the second strength tube;

wherein at least one of the steps of forming the first strength tube and forming the second strength tube comprises:

arranging a unitary sheet of strength material so that a width of the sheet extends in a hoop direction of the respective one of the first strength tube and the second strength tube, the sheet of strength material comprising chopped strands of fiber gathered into bundles, the bundles being oriented generally parallel to one another and distributed along the sheet of strength material, each of the bundles extending in a direction from the first longitudinal edge margin to the second longitudinal edge margin of the sheet of strength material; and

joining first and second longitudinal edge margins of the sheet together in overlapped relation to form a longitudinal overlap portion extending parallel to a length of the respective one of the first strength tube and the second strength tube at a seam, the seam being constructed to hold the first longitudinal edge margin from moving in a circumferential direction relative to the second longitudinal edge margin as the liner is stretched radially from the first external diameter to the second external diameter.

19. A method as set forth in claim **18**, wherein the at least one of the steps of forming the first strength tube and forming the second strength tube further comprises needle punching the chopped strands of fiber between two layers of felt.

20. A method as set forth in claim **18**, further comprising flame bonding the at least one felt tube to each of the first strength tube and the second strength tube.

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